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# Dual Use Ground Vehicle Condition-Based Maintenance Project B


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GROUNDED IN MICHIGAN REACHING FOR THE FUTURE

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**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

# Project Objectives

- **Fatigue sensor for structural components** - *design, fabrication and testing*
- **Lubricant condition monitoring** - *sensor selection, experimentation and laboratory evaluation*
- **Wireless communication system** – *design and develop a sensor network*
- *Demonstration of a prototype system in a dual-purpose vehicle*

# Project Team

## Principal Investigators:

**Dr. Muralidhar Ghantasala** - Sensors, fabrication, data acquisition and testing

**Dr. Claudia Fajardo** - Engine lubricant condition monitoring

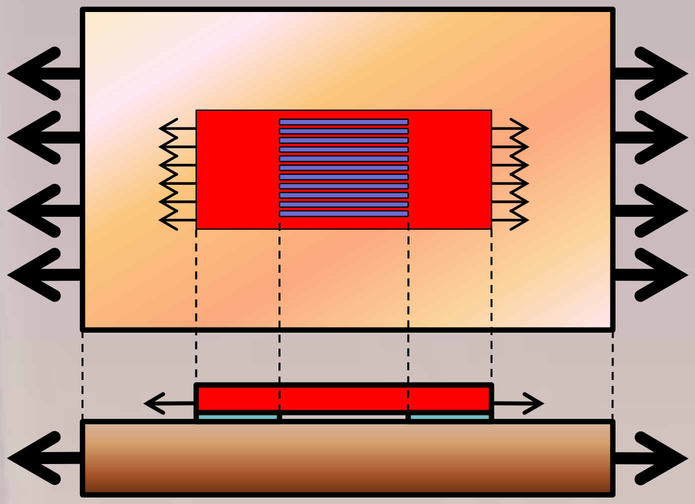
**Dr. Ajay Gupta** - Wireless communication subsystem-design, interfacing, testing and evaluation

**Dr. Daniel Kujawski** - Fatigue sensor-design, simulation, testing

## Students:

Subash Gokanakonda – Fatigue sensor
Ryan J. Clark – Lubricant condition monitoring
Andrew Hovingh & Madhuri Revalla - wireless networking

# How a fatigue sensor works?

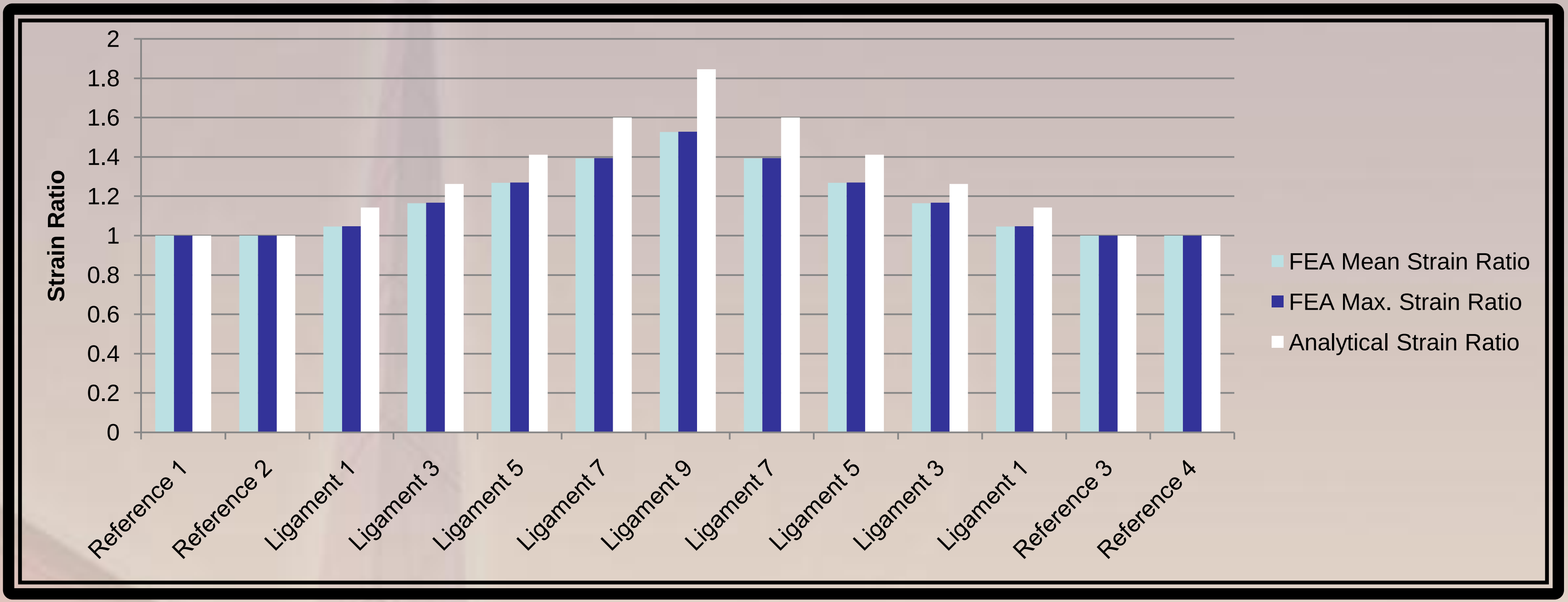


- Detects and monitors the fatigue damage at a critical location
- Strains in ligaments resemble the actual strain field at a critical location
- Ligaments fail due to fatigue in a sequence from the ligament experiencing the highest to the lowest strains

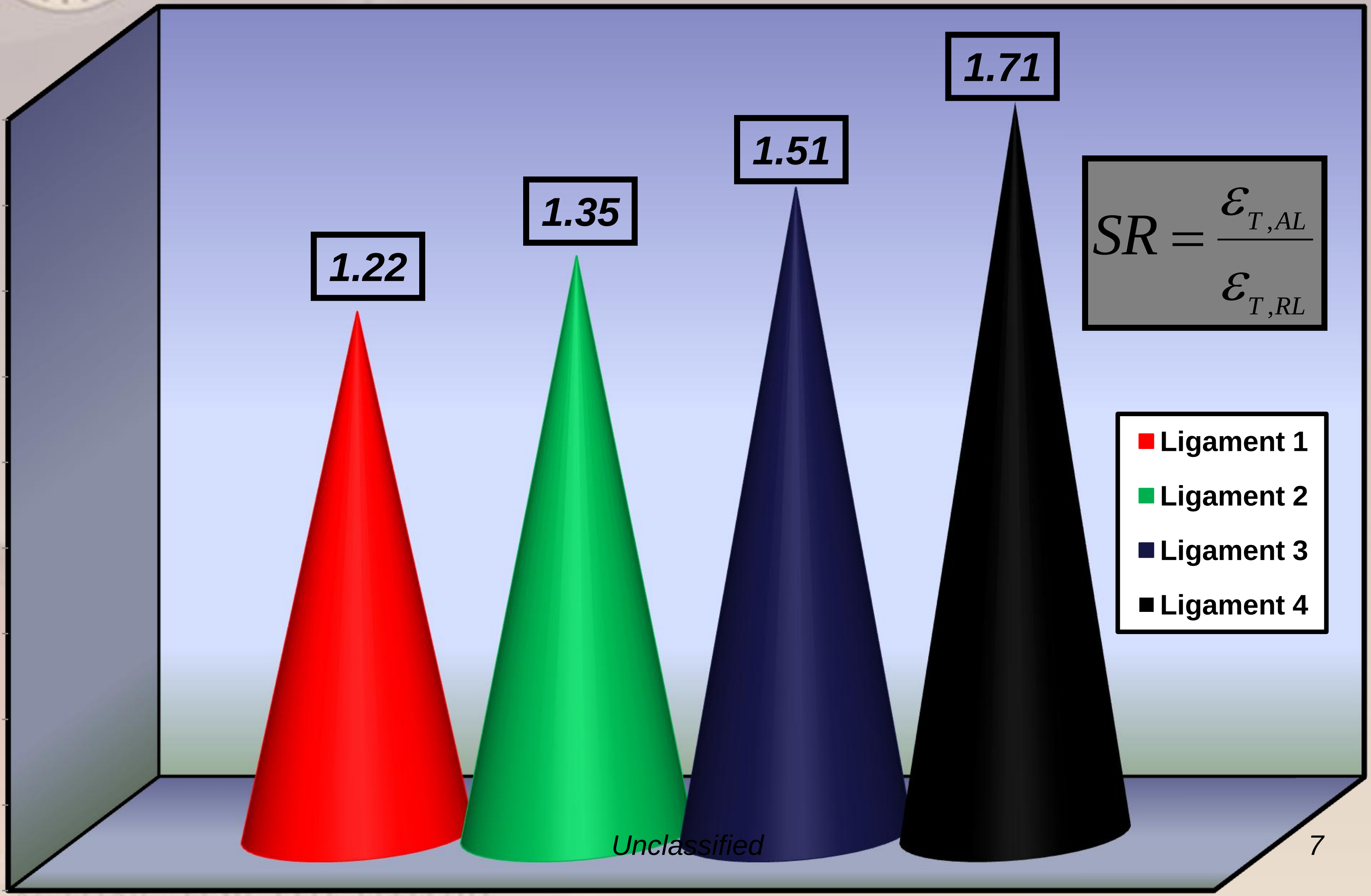
# Important Characteristics

- Placed at a suitable distance from a critical location
- Made from the same material or different material than that of the structure
- Used on new structures or on those already in service
- Experiences same cyclic strains and environmental conditions as the critical location
- Enables real-time on-board fatigue life monitoring
- Supports **C**ondition **B**ased **M**aintenance (CBM)

# Strain Magnification: Comparison



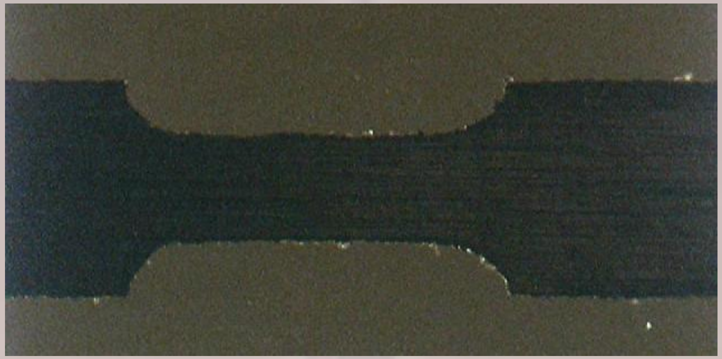
# Strain Ratio

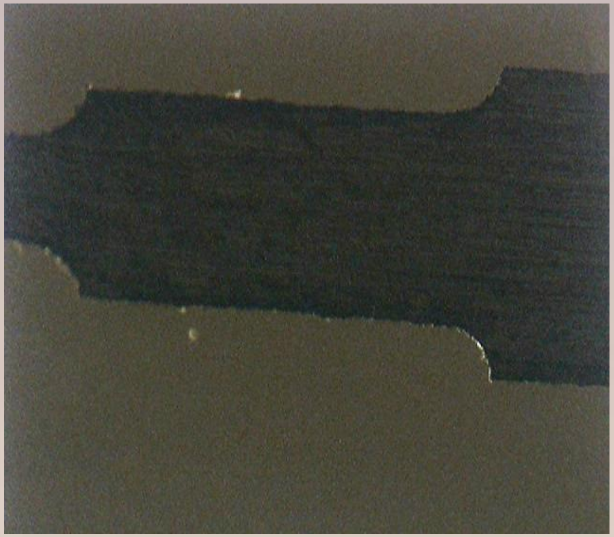


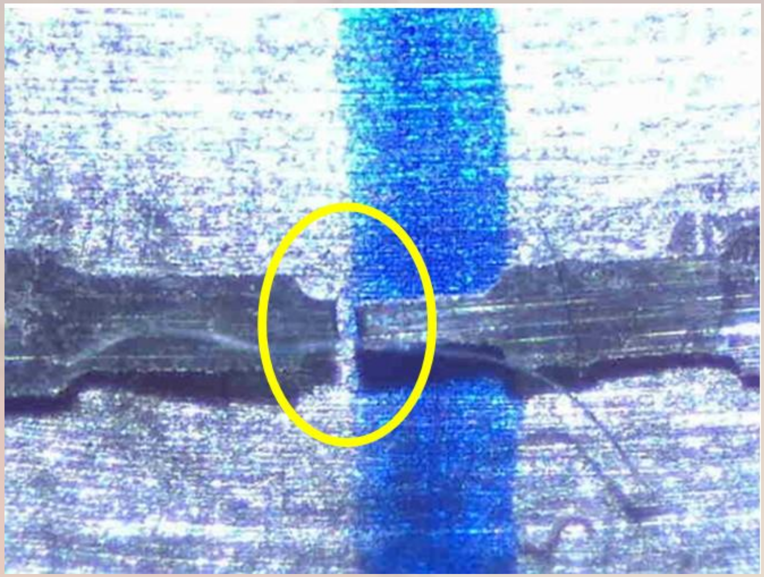

$$SR = \frac{\varepsilon_{T,AL}}{\varepsilon_{T,RL}}$$

# *Fatigue sensor (active part) in Stainless Steel*

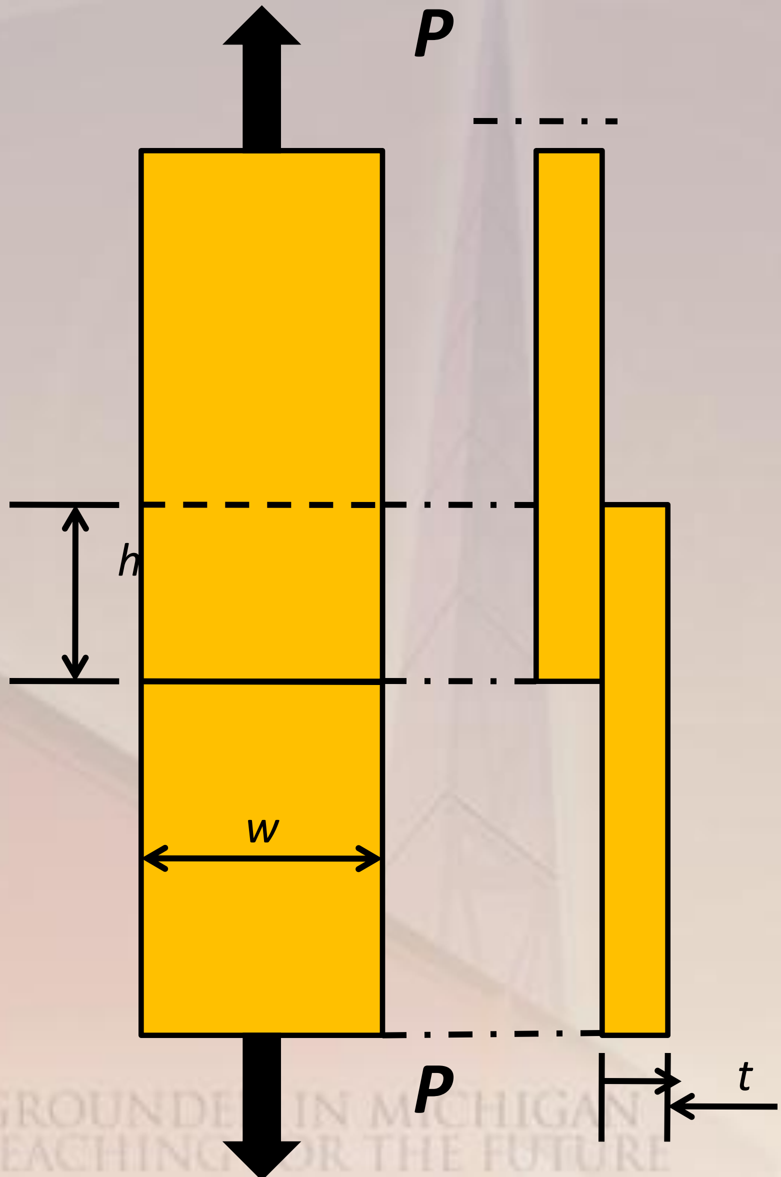
***$L_g$ = 1 mm H = 4.5 mm***







# Glue-Adhesive Testing




*Shear strength,*

$$\tau_{Test} = \frac{P}{(h * w)}$$

*Normal stress,*

$$\sigma_{test,normal} = \frac{P}{(w * t)}$$

# Work Plan

- FEA simulations are being conducted using an elastic-plastic material model
- The properties of the adhesives for gluing the fatigue sensor on to test structures are under investigation
- Different manufacturing techniques are being evaluated. The first set of sensors will be manufactured using milling and laser machining

# Lubricant Condition Monitoring Strategies

- Goal
  - Quantify the degree and rate of oil degradation in a JP-8 fueled diesel engine through *direct, on-board monitoring of lubricant properties*
- Objectives
  - Establish correlations between contamination levels and changes in lubricant properties
  - Validate the relationship between published threshold limits on contaminant level and lubricant properties
  - Determine the effect of engine operating conditions on lubricant properties

# Equipment

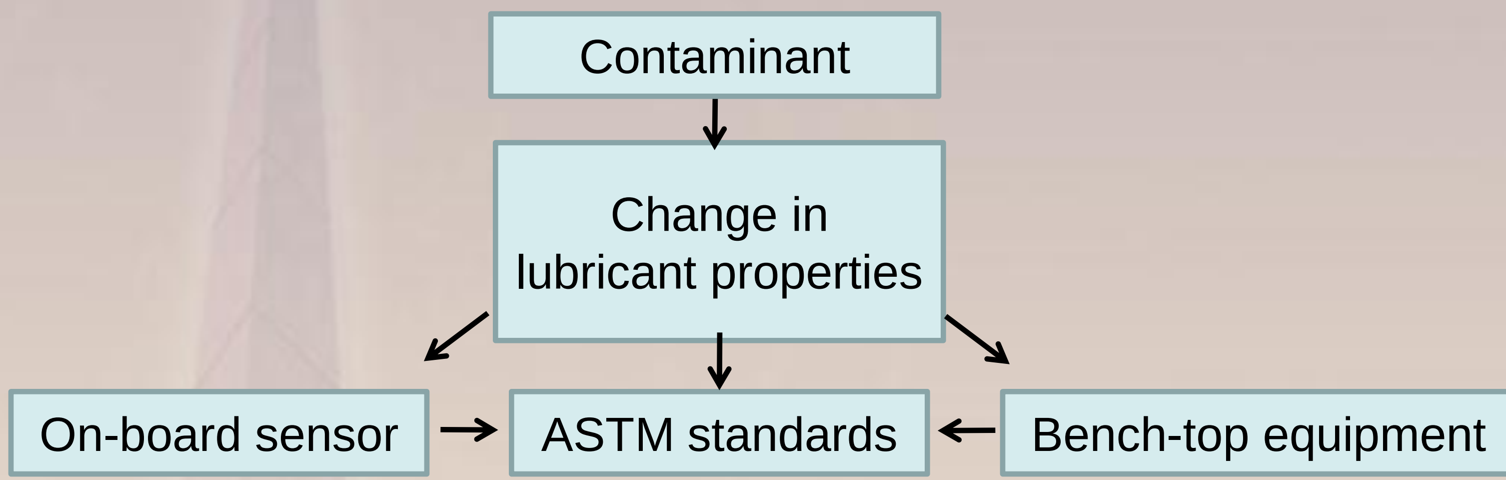
- **Engine**
  - Naturally-aspirated, 6.5 Liter (detuned) V-8 diesel
  - Coupled engine-dynamometer setup and instrumentation
- **Lubricant-condition monitoring sensor**
  - Temperature (-40 °C < T < +150 °C)
  - Dynamic viscosity (0 < μ < 50 cP)
  - Dielectric constant (1 < κ < 6)
  - Density (0 < ρ < 1.5 g/cm$^3$)
- **Mounting location**
  - Ensure sufficient fluid contact with sensor

Engine

Lubricant sensor

# Benchmarking Experiments

- Bench-top
  - Assess contaminant effects (e.g. fuel, water, soot) on lubricant properties
  - Validate sensor output against ASTM standards




- Engine
  - Monitor lubricant properties directly with the oil-condition sensor
  - Validate sensor output and identify contaminants

# Results: Validation of Prototype Sensor Output

Baseline measurements

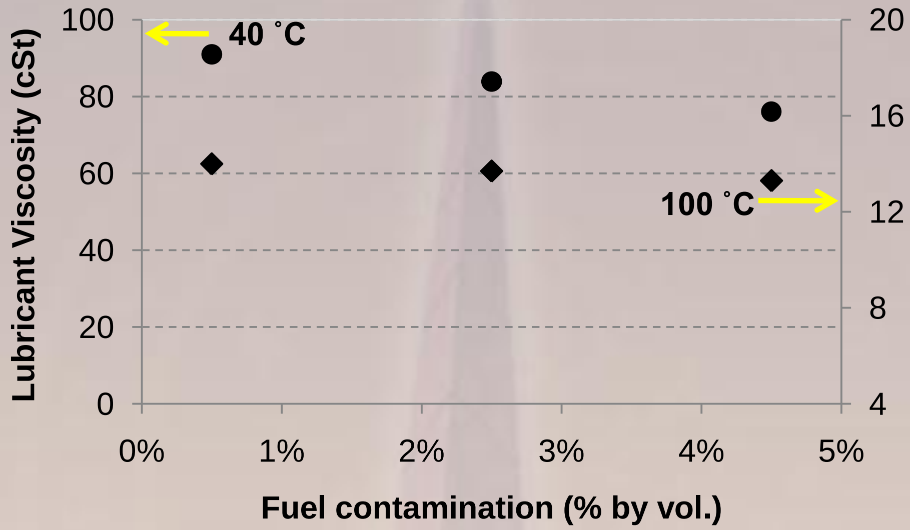
| Property | Sensor | Validation | Mfr. Spec. | Difference% (validation vs. MS) | Discrepancy (sensor vs. validation) |
|---|---|---|---|---|---|
| Viscosity at 40 ˚C (cSt) | 96.2 +/- 0.9 | 123.2 +/- 0.1 | 118 | 4% | 21.9% |
| Viscosity at 100 ˚C (cSt) | 14.1 +/- 0.7 | 15.2 +/- 0.7 | 15.7 | 3% | 7% |
| Dielectric const. at 40 ˚C | 2.22 +/- 0.01 | 2.38 +/- 0.01 | n/a | n/a | 6.7% |
| Flash Point (˚F) | n/a | 419 +/- 5 | 415 | 1% | n/a |

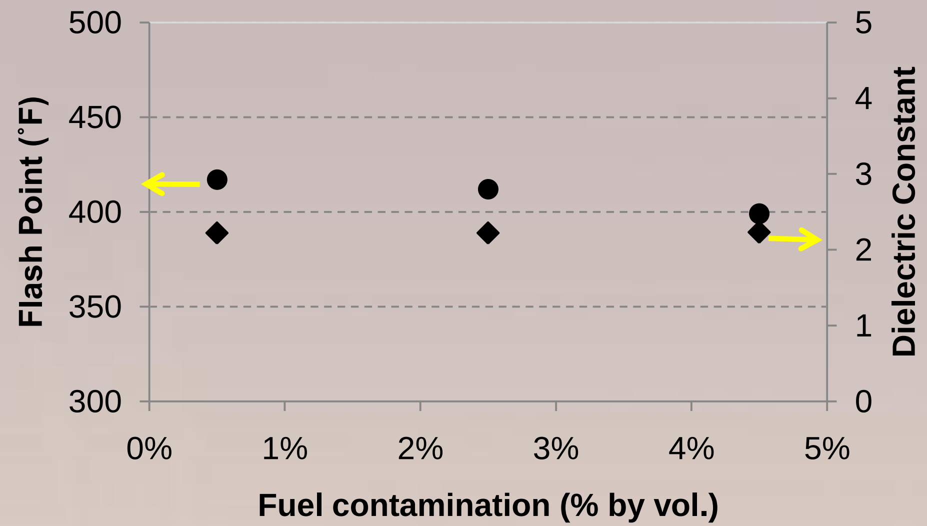
Lubricant contamination (2.5% fuel by vol.)

| Property | Sensor Output | Validation Measurement | Discrepancy (sensor vs. validation) |
|---|---|---|---|
| Viscosity at 40 ˚C (cSt) | 89.1 +/- 0.7 | 117 +/- 0.4 | 23.7% * |
| Viscosity at 100 ˚C (cSt) | 13.7 +/- 0.1 | 14.3 +/- 0.1 | 5% |
| Dielectric const. at 40 ˚C | 2.22 +/- 0.02 | 2.39 +/- 0.01 | 7% |
| Flash Point (˚F) | n/a | 412 +/- 1 | n/a |

- Very good precision established
- Discrepancy between sensor output and bench-top measurements ≤ 7% for viscosity at 100 °C and dielectric constant
- Investigating discrepancies for viscosity measurement at 40 °C

# Results (continued)




- Decrease in viscosity with increasing temperature
- Decrease in viscosity with fuel contamination
- Decrease in flash point with fuel contamination
- No change in dielectric constant for 2.5% vol. fuel contamination

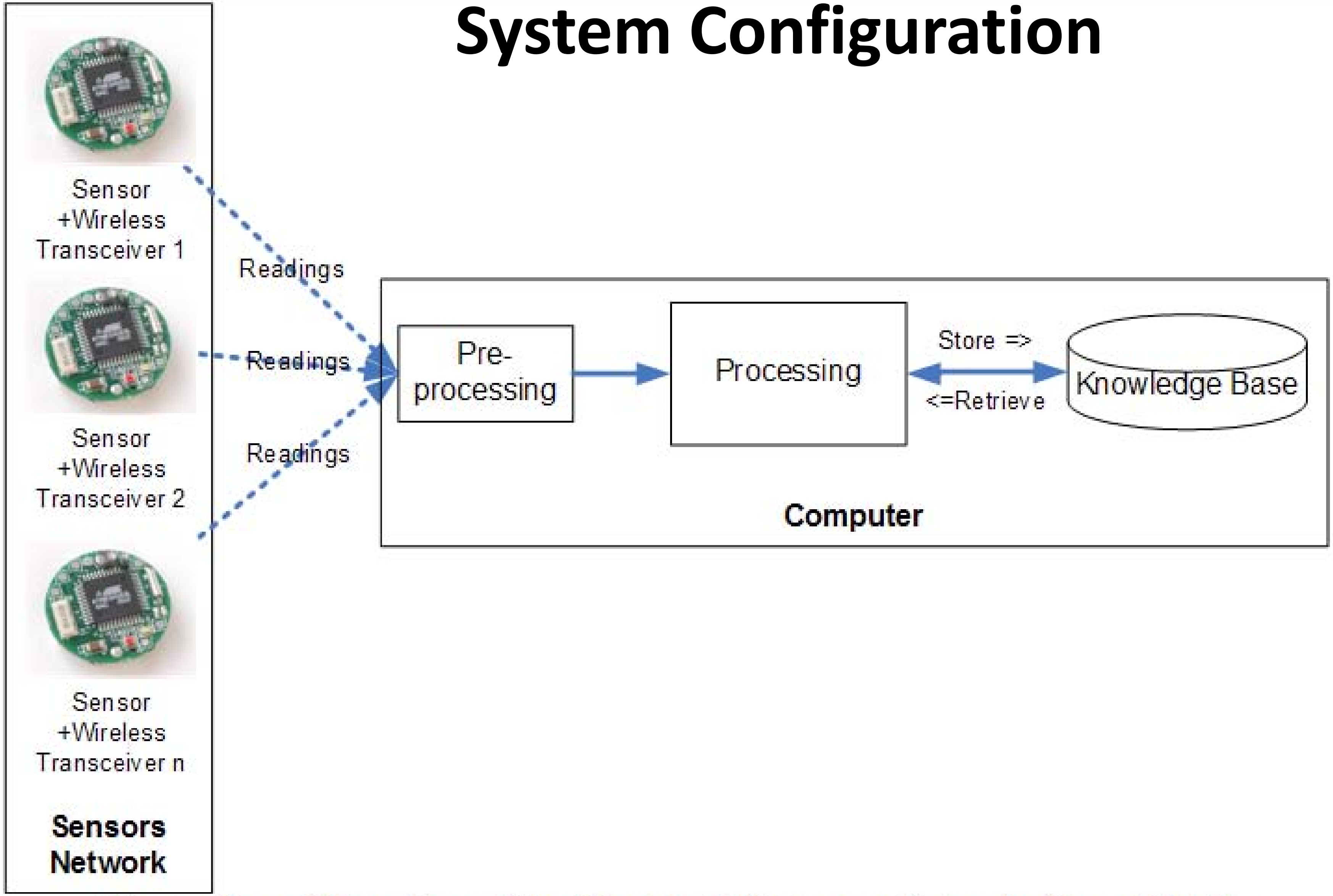
# Wireless Communication Strategy

## Objectives

- Design a wireless, self-sufficient, low-power, scalable and cost-effective sensor-data communication system using off-the-shelf devices (microcontrollers, radio transceivers, amps, A/D converters…) for ground vehicles

- Build a prototype of wireless network system that stores and displays sensor data from the engine and structural components

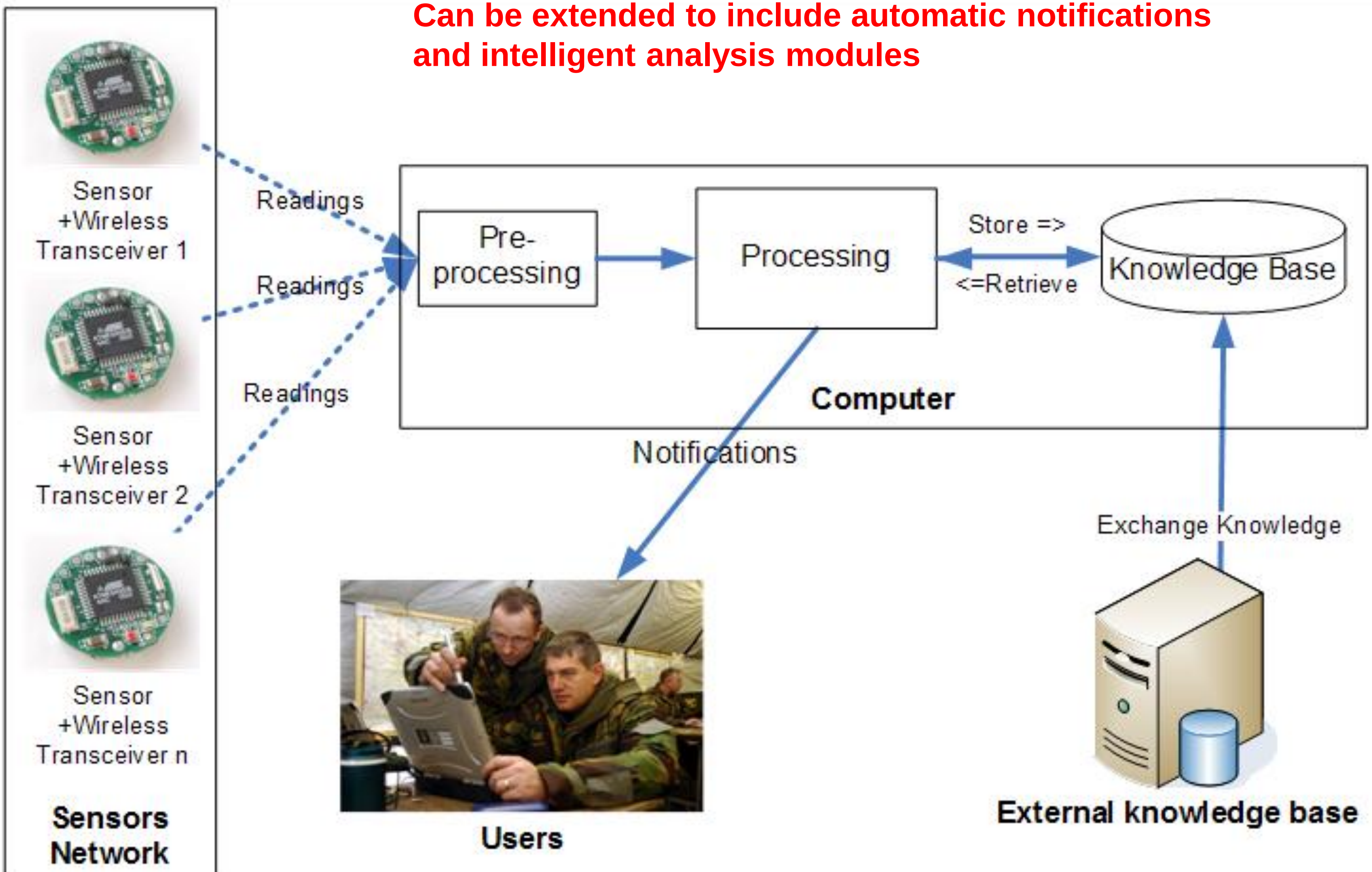
# System Configuration




Wireless Sensor Network-based Condition-Based Maintenance System for Ground Vehicles

# System Configuration

**Can be extended to include automatic notifications and intelligent analysis modules**




**Wireless Sensor Network-based Condition-Based Maintenance System for Ground Vehicles**

# Evaluated Device Configurations

- Texas Instrument’s MSP430 micro-controller + Chipcon transceiver
  - Inexpensive, configurable
  - Low level programming (more software development time)
- Crossbow’s MICA motes
  - Integrated controller + radio, costlier
  - NesC programming (less development time)
- Characteristics
  - Low power, low duty-cycle (on/off)
  - 900MHz and 2.4GHz bands
  - Communication standards: 802.15.4 and ISM band compliant and ZigBee ready

# Challenges

- Harsh environments (e.g. high temperature)
  - MSP430, CC chips, and Crossbow motes can tolerate up to 185ºF
- Connectivity
  - Interference (with other communication equipments, and other transceivers)
  - Signal degradation (Faraday cage effect from the vehicle, temperature-resistant enclosures)
- Fault-tolerance
  - Provide built-in redundancy in the communication network

# Summary

1. **Fatigue sensor design** – First stage of the design and numerical simulation has been completed. Manufacturing strategies are being explored.

2. **Lubricant monitoring sensor has been identified.** Literature review has been completed. A dual-purpose diesel engine has been procured and is being set-up with the required instrumentation.

3. **Wireless communication strategies are being evaluated.** Texas Instrument's MSP430 microcontroller- based and Crossbow's motes- based systems are shortlisted for further evaluation. Simple system configurations are being tested in the laboratory.

# Thank you

Unclassified